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AN INTERACTING GALAXY PAIR IN THE BOOTES VOID

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ABSTRACT

We report the first identified pair of interacting galaxies in the Bootes void. The galaxies, CG 692 (IRAS 1519+5050) and CG 693, have redshifts 0.0572 and 0.0575, respectively, and a mutual separation of ~34 kpc. CG 692 is experiencing widespread star formation, at a rate estimated to be 18.4 $M_{\odot}$ yr^{-1}. CG 693 is a Seyfert 1, the third AGN found in the Bootes void, with a small amount of extranuclear star formation. The pair is another example of interacting galaxies displaying starburst and Seyfert activity apparently triggered by the interaction.

Subject headings: galaxies: interactions — galaxies: Seyfert — galaxies: starburst

1. INTRODUCTION

The Bootes void (Kirshner et al. 1981) is one of the best-studied low-density regions in the universe. At least 20 resident galaxies have been identified; two are active galactic nuclei and the rest are undergoing significant amounts of star formation (Osterbrock & Dahari 1983; Tifft et al. 1986; Moody et al. 1987; Strauss & Huchra 1988; Weistrop & Downes 1988; Weistrop 1989; Dey, Strauss, & Huchra 1990, hereafter DSH). As part of a program to investigate the nature of galaxies in voids, we have obtained emission-line images of a sample of Bootes void galaxies. We report here our results for two of those galaxies, a spiral undergoing large amounts of star formation, which is interacting with a previously unidentified Seyfert 1 galaxy. This system constitutes the first known pair of interacting galaxies in the Bootes void.

The *IRAS* source 1519+5050, identified with the northwest of two adjacent galaxies, has a redshift placing it in the Bootes void (DSH). 1519+5050 is cataloged as CG 692 (R.A. = $15^h19^m36^s.6$, Decl. = $+50°51'.0$ [1950]) by Sanduleak & Pesch (1987). Its companion is CG 693 (R.A. = $15^h19^m38^s.0$, Decl. = $+50°50'.8$ [1950]). These galaxies were misidentified as CG 693, CG 693A, respectively in Weistrop, et al. (1991). Zwicky & Herzog (1966) describe the pair as "double system, tidal effects" at R.A. = $15^h19^m.6$, Decl. = $+50°52'$. Both galaxies are considerably brighter in Hα images taken at the redshifted wavelength for CG 692 than in the nearby continuum band images. Our spectra confirm that the two galaxies have essentially the same redshift and lie within the Bootes void (Kirshner et al. 1987).

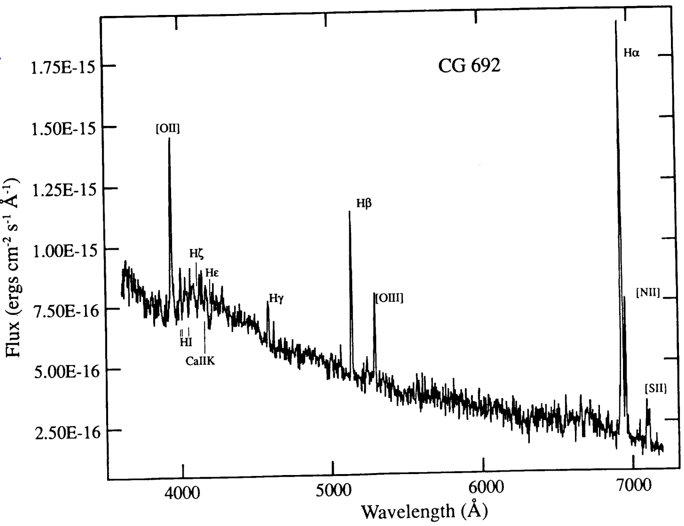
2. SPECTROSCOPY

Spectra for CG 692 and CG 693 were obtained using the "Blue Channel" spectrograph 16 April 1991 at the Multiple Mirror Telescope located on Mount Hopkins, AZ. The spectrograph is a dual aperture instrument with a Reticon detector (Foltz & Ouellette 1989). The 300 g mm^{-1} grating produces a resolution of 12 Å FWHM for an unresolved emission line observed through the 2″ × 3″ slit used. Exposure times were 600 s on CG 692 and 900 s on CG 693. Reductions included linearization of the spectra, wavelength calibration, correction for pixel-to-pixel variations and for extinction, sky subtraction, and flux calibration.

The spectrum of CG 692 is typical of a galaxy undergoing large amounts of star formation. Strong, narrow emission lines are present as well as absorption features due to hydrogen and Ca II (Fig. 1). The presence and relative strength of the Ca II K line suggest that the Hε line may be blended with Ca II H absorption and that the stellar population has a significant component of A and/or early F stars. The heliocentric velocity, calculated from the emission lines, is 16,972 km s^{-1}, in good agreement with the 16,709 km s^{-1} found by DSH. The redshift, corrected for the Earth's motion around the Sun and the Sun's motion around the Galaxy, is 0.0572.

The observed emission line fluxes are given in Table 1. Formal errors in the fluxes, calculated from the uncertainty in the continuum flux measurement, range from 3%–15%. These values do not include possible systematic errors arising in calibration or due to poor weather conditions (see footnote Table 1). Ratios of emission-line strengths are often used to identify the source of the ionizing radiation in emission-line galaxies (Baldwin, Phillips, & Terlevich 1981; Veilleux & Osterbrock 1987). Common line ratio diagnostics include log ([O III] λ5007)/Hβ λ4861) plotted against log ([N II] λ6583)/(Hα λ6563), log ([S II] λ6716 + λ6731)/(Hα λ6563), or log ([O II] λ3727)/([O III] λ5007). In all of these diagrams, the reddening corrected ratios for CG 692 are located well within the area defined by H II regions or H II region–like galaxies, even taking into account the uncertainty in the line ratios, ~±20% (Baldwin et al. 1981; Veilleux & Osterbrock 1987). In calculating the line ratios, the hydrogen fluxes were not corrected for absorption in the underlying galaxy spectrum. Correction

[1] Observations reported in this paper were obtained at the Multiple Mirror Telescope Observatory, a joint facility of the University of Arizona and the Smithsonian Institution.



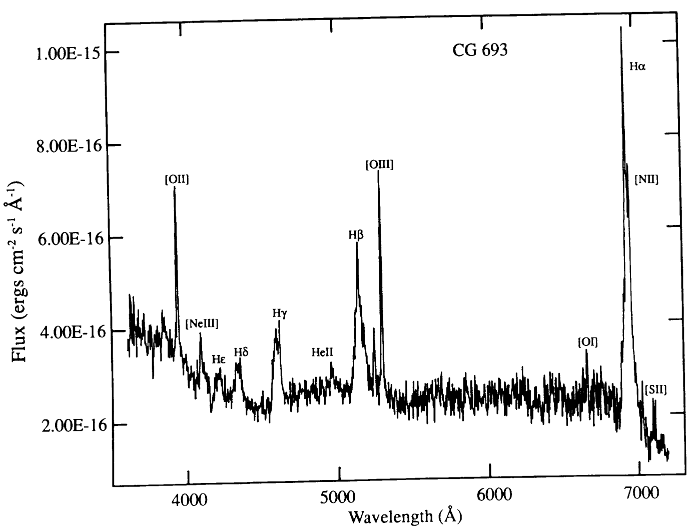


FIG. 1.—Spectra of the Bootes void galaxies CG 692 (*top*) and CG 693 (*bottom*). Note the absorption due to high Balmer transitions and Ca II K in CG 692 and the broad hydrogen lines in CG 693.

for the absorption would increase the strength of the H lines, moving CG 692 within the region occupied by H II region-type galaxies, but would not change the conclusions concerning the source of the ionizing radiation. The line ratios indicate CG 692 is undergoing large amounts of star formation, a conclusion supported by the narrow-band imaging discussed in the next section. The continuum flux of this galaxy increases steeply toward short wavelengths, again suggesting the presence of hot young stars.

The spectrum of CG 693 has the strong, broad hydrogen emission lines ($\sim 3 \times 10^3$ km s^{-1} FWHM) and narrow forbidden lines typical of a Seyfert 1 galaxy (Fig. 1). The flux for Hα is uncertain (indicated by a colon [:] in Table 1) since at this dispersion the broad Hα line is blended with [N II] λ6548 (if present) and λ6583. No flux is measured for Hγ since it appears to be blended with [O III] λ4363. The continuum increases shortward of 4000 Å, due either to the presence of very hot, young stars or the nonthermal ionizing continuum. CG 693 is the third galaxy with an active nucleus to be identified in the Bootes void; Mrk 845 was identified as a Seyfert 1 and I Zw 81 as a low-ionization nuclear emission line region (LINER) (Osterbrock & Dahari 1983).

The redshift of CG 693, corrected for the Earth's motion around the Sun and the Sun's motion around the galaxy, is 0.0575 (heliocentric velocity 17,080 km s^{-1}). The redshifts for CG 692 and CG 693 agree within the uncertainty of the line measurements, $\sigma_z = \pm 0.0003$, and we conclude the two galaxies are at the same distance.

TABLE 1

RELATIVE EMISSION-LINE FLUXES[a] OF CG 692/693

Line	CG 692	CG 693
[O II] λ3727	154	32
Hδ		36
Hγ	29	
He II λ4686		6.8:
Hβ	100[b]	100[b]
[O III] λ4959	14	13
[O III] λ5007	49	43
[O I] λ6300		9.2
[N II] λ6548	30	
Hα	295	214:
[N II] λ6583	85	24:
[S II] λ6717	27	5.2
[S II] λ6731	25	3.7

[a] All fluxes relative to Hβ.

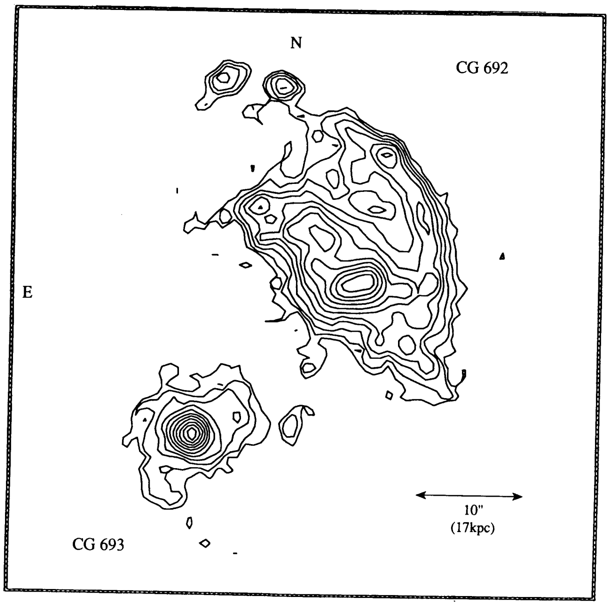
[b] The absolute Hβ fluxes are 7.52×10^{-15} ergs cm^{-2} s^{-1} for CG 692 and 1.32×10^{-14} ergs cm^{2} s^{-1} for CG 693. These values are uncertain due to nonphotometric observing conditions and aperture losses around the spectrograph slit. Comparison of the Hα absolute fluxes obtained from the spectra with those obtained from the imaging data indicate agreement within ±15%.

3. IMAGING

Images were obtained using the Goddard Fabry-Perot Imager (FPI) U.T. 1991 April 7 on the University of Arizona's 90 inch (2.3 m) telescope at Kitt Peak. The FPI consists of a field lens, a collimating lens (fl = 308 mm), blocking filters and Fabry-Perot etalon in the parallel beam, a reimaging lens (fl = 200 mm), and a TEK 512 × 512 antireflection coated CCD chip. The FPI was tuned to a FWHM of 17.2 Å at the redshifted Hα wavelength of the galaxies. Observations were also obtained in a nearby continuum band. The blocking filter, centered at 6891 Å with a FWHM of 102 Å, was used to eliminate adjacent Fabry-Perot orders. Three images, with integration times of 300 s each, were taken on- and off-band.

Each CCD frame was corrected for bias, dark counts, and pixel-to-pixel variations. Images taken at the same wavelength (on- or off-band) were registered and combined with a median filter to remove cosmic-ray events. Images of the calibration star HZ 44, observed the same night through the same FPI transmission settings, were similarly processed.

Due to the narrow bandpass of the FPI and the strength of the Hα emission relative to the [N II] lines (Table 1), contamination of the Hα images by the [N II] emission is minimal and not considered further. The continuum band was observed at wavelength 6868 Å. We cannot rule out the possibility that the continuum image of CG 693 is slightly contaminated by the emission from the broad Hα-[N II] complex.



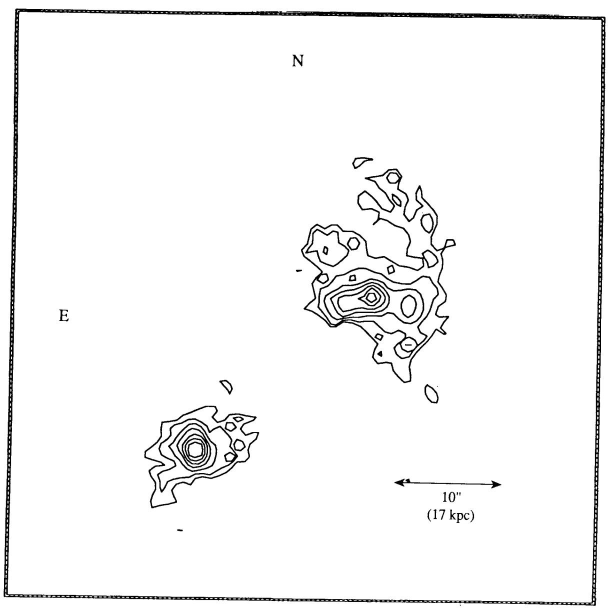


FIG. 2.—Contour plots of the redshifted Hα (*top*) and continuum (*bottom*) images of CG 692/693. The outermost contour represents the pixel flux 2 σ above sky. Successive contour levels increase by a factor of 1.5. The maximum contour in the Hα image is 7.7×10^{-16} ergs cm^{-2} s^{-1} $pixel^{-1}$, while the maximum contour in the continuum image is 2.1×10^{-16} ergs cm^{-2} s^{-1} $pixels^{-1}$. The image scale is 0".41 $pixel^{-1}$.

Contour plots of CG 692/693 are shown in Figure 2. The distance between the points of maximum emission on the continuum image is 20".6, corresponding to 34 kpc ($H_0 = 50$ km s^{-1} Mpc^{-1} assumed throughout this paper). Since the redshifts of the galaxies are identical within their uncertainty, it is likely these galaxies are interacting. CG 692/693 is an example, in a low-density region, of the common phenomenon of a close pair of galaxies experiencing starburst and Seyfert activity triggered by the interaction (Keel et al. 1985).

The disturbed morphology of CG 692 supports the conclusion that the galaxies are interacting. Northwest of the nucleus, there is a pronounced spiral arm which is undergoing a considerable amount of star formation. There is a bright Hα knot near the end of the continuous arm and two disconnected Hα knots beyond that. There are also two faint Hα features between the galaxies which may be a result of the interaction (compare images of NGC 3395/6 in Keel et al. 1985). There are several interesting features within the central region. The fainter contours are generally oriented in a NE-SW direction, while the brightest contours in the nucleus are extended E-W in both the on- and off-band images. The elongated, barlike shape of the nucleus may be due to the interaction of the galaxies. Extending ~5 kpc NE of the nucleus is a jetlike region of Hα emission which could be the stub of a spiral arm. There is also a relatively bright region of Hα emission directly N of the stub, 8 kpc from the nucleus. The region is visible although faint in the continuum image. We conclude the central region of CG 692 is undergoing massive amounts of star formation at several locations.

We have previously suggested that CG 692 is a ring galaxy (Weistrop et al. 1991), but close examination of the image indicates that the ring structure is illusory, caused by the angle at which the continuum emission from the prominent spiral arm is observed.

CG 693 is well resolved, with one spiral arm extending south from the east side of the nucleus and a second arm extending northwest from the nucleus. The arms are present in both the on- and off-band images. Examination of the on-band minus off-band image (not shown) suggests there is a small amount of Hα emission from the NW arm.

4. DISCUSSION

The Hα flux can be used to estimate the rate of star formation in CG 692 (Kennicutt 1983). The conversions from observed count rates to fluxes are obtained from the observations of HZ 44. The Hα flux for CG 692 is 1.38×10^{-13} ergs cm^{-2} s^{-1}, with a ±25% error due to the uncertainty in the conversion from count rate to flux. Almost all the Hα emission from CG 693 arises in the nucleus, presumably due to activity associated with the central engine, so no star formation rate is estimated for this galaxy. Since the galaxies are located at $b = 53°$, absorption within our Galaxy is ~0.02 mag and has been ignored (Kennicutt & Kent 1983). Assuming $q_0 = 0$, the Hα luminosity of CG 692 is $L = 2.06 \times 10^{42}$ ergs s^{-1}, almost twice that of the most luminous normal galaxies (Kennicutt & Kent 1983), but similar to the Hα + [N II] luminosities of the brightest interacting galaxies (Kennicutt et al. 1987). Peimbert & Torres-Peimbert (1992) have estimated lower limits to the Hα luminosity for 10 Bootes void galaxies. Even allowing for their factor of 2 underestimate, the Hα luminosity for CG 692 is brighter than the Hα luminosities for all their void galaxies except CG 657. Our Hα luminosity has not been corrected for reddening internal to the galaxy nor for Hα absorption due to the underlying stellar spectrum. The star formation rate in CG 692 is 2.9 $M_\odot$ yr^{-1} in the $M \geq 10$ $M_\odot$ range and 18.4 $M_\odot$ yr^{-1} in the $0.1 \leq M \leq 100$ $M_\odot$ range (Kennicutt 1983).

It is difficult to assess the significance of a single pair of interacting galaxies in the Bootes void. Studies of emission-line galaxies indicate ~8% of those galaxies are interacting pairs (Salzer, MacAlpine, & Boroson 1989), predicting one to two pairs in a sample of 20 galaxies. This suggests the frequency of interacting pairs in the Bootes void is similar to that in emission-line galaxies in more densely populated regions and that the mechanism that produces interacting galaxies is independent of galaxy density. The role of selection effects in this conclusion is complex and exacerbated by the problems associated with small number statistics. At the redshift of the Bootes void, the *IRAS* catalog may be dominated by interacting pairs (Xu & Sulentic 1991), while the sample of optically selected galaxies in the Bootes void is incomplete. Until these effects are better understood, it is premature to draw conclusions from one system concerning the frequency of interacting galaxies as a function of galaxy density.

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